VOLUME 81 SEPARATE No. 706

PROCEEDINGS

AMERICAN SOCIETY
OF
CIVIL ENGINEERS

JUNE, 1955

GENERAL ASPECTS OF PLANNED GROUND WATER UTILIZATION

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IRRIGATION AND DRAINAGE DIVISION

{Discussion open until October 1, 1955}

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Printed in the United States of America

Headquarters of the Society
33 W. 39th St.
New York 18, N. Y.

PRICE $0.50 PER COPY

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This paper was published at 1745 S. State Street, Ann Arbor, Mich., by the American Society of Civil Engineers. Editorial and General Offices are at 33 West Thirty-ninth Street, New York 18, N. Y.

GENERAL ASPECTS OF PLANNED GROUND WATER UTILIZATION

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SYNOPSIS

This paper briefly reviews the legal status of ground waters in California; discusses the present development of ground-water supplies with particular reference to current problems caused by haphazard development; recommends a suitable organization for full beneficial control and use of available water supplies through the coordinated use of surface and ground-water storage capacity; discusses briefly the probable outstanding problems of such coordinated operation; and concludes with an illustrative operational example of the benefits attributable to the planned utilization of underground storage.

HISTORICAL RESUME

Legal principles applicable to rights in, control, and use of, ground-waters in California rest almost entirely on the foundations established by court decisions. There was no mention of water rights in the 1849 constitution, nor in legislation directly relating thereto prior to the codes, adopted in 1872, but at the first legislative session held in 1850, it was enacted that the common law of England, as developed by the courts of that country, would constitute the rule by which the California courts would be guided in their decisions in situations not otherwise provided for. Consonant with that directive, the California courts, in the earliest cases, applied the English doctrine of absolute ownership of underlying ground water on the part of the owner of overlying land. This was later over-ruled and another doctrine substituted in which various modifications of the harsh "absolute ownership" theory were announced, many of the modified decisions resting on strained interpretations and definitions of physical facts and occurrences.

Historically, the courts have always attempted to differentiate between waters flowing in subterranean streams through "known and definite channels" and percolating waters. Those waters flowing in definite underground streams have been made subject to the same laws regarding rights of use as streams flowing on the surface. In making this distinction the courts have been at variance with hydrologic principle which recognizes that all groundwater (with minor exceptions such as unrecoverable soil moisture, waters in closed basins which are dissipated by excessive evapo-transpiration, etc.) constitutes a part of the general water supply and has a common ultimate disposal with surface streams by means of outflow to the ocean or other large body of water, becoming indistinguishable from surface flows in the process. In other words, all ground water eventually contributes to the maintenance of the surface supply.

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In 1903 the California Supreme Court first definitely abrogated the English rule of absolute ownership in the leading case of Katz v. Walkinshaw, 141 Cal. 116. The principles enunciated therein, and further developed in subsequent decisions, have come to be known as the doctrine of correlative rights, and are comparable in many respects to the riparian doctrine as applied to surface waters. The principle that all owners of overlying lands are entitled to the reasonable use of the waters occurring under the lands was established, with the further corollary that no owner was entitled solely by virtue of the right of ownership to injure other owners by unreasonable diversions for the purpose of 'sale or carriage to distant lands'. Many subsequent decisions amplified and extended this theory, a late leading decision being the case of City of Pasadena v. City of Alhambra, et al. 33 Cal. 2d 908, wherein it was declared that where the common supply was insufficient to provide for the needs of all users, those who had acquired prescriptive rights by use for a period of five years would, under the theory of "mutual prescription", so-called, be required to share equitably the burden of reducing the demand to the hydrologically determined safe yield. The decision was largely influenced by a stipulation by all but one of the parties involved, which included a physical solution providing the necessary water supply to meet the needs of the water users.

Although the use of ground water in California has been one of the major factors contributing to the development of the State, and the gross pumpage is estimated to be in excess of 10,000,000 acre-feet per year (roughly 40% of the gross pumpage in the United States) there has been neither constitutional nor legislative control of the development of this basic resource except in minor instances - such as control of unreasonable manner of use or wastage from wells tapping artesian supplies. Consequently, all disputes or differences of opinion regarding right and equities, based upon the use of ground water, have been referred to the courts for decision, an expensive and time consuming process definitely not contributing to the development of firm policies governing ground-water development. The principal beneficial result of such legal action is that it is possible, as in the case of Pasadena v. Alhambra, supra, to effect through the courts a determination of rights among all users from a common basin. However, such a procedure is usually initiated long after it is needed, must be commenced by one or more of the users, and eventuates in a decision which may be delayed until long after severe damage has been suffered by the basin. Such decisions relate only to the respective rights of each user and provide no means of instituting possible hydrologically feasible plans concerned with possible alteration of the regime of use within the basin nor do they necessarily provide for the most economic and beneficial use of imported supplies.

There have been, however, two developments in California water law which appear to presage an awakening in the public consciousness to the desirability of establishing a program looking to the maximum utilization for beneficial use of all the waters of the State, both surface and underground. The first was the passage, in 1928, of a constitutional amendment recognizing riparian rights but limiting them to reasonable use under reasonable methods of use. The amendment has been referred to and applied by the courts in enunciating the reasonable use doctrine as being applicable to overlying users from a ground-water basin.

The second development was the recognition by the courts that the storage of water underground for later withdrawal by the entity storing such waters, as provided for in the Water Code, was a beneficial operational use of such

storage capacity. This principle was brought forth in the case of City of Los Angeles v. City of Glendale, 23 Cal. 2d 68, wherein the points decided included the instance where water was imported by the City of Los Angeles from a distant watershed, Owens Valley, and spread in the San Fernando Valley, either through sale of water for irrigation, or otherwise, so that the water eventually found its way into an underground lake forming a part of the Los Angeles River, in due course reaching the diversion works by which the City takes water into its distribution system. The court declared that the City, in spreading water in the San Fernando Valley with the expectation that the water would in due time be recaptured, did not abandon the water nor was it free to be taken by others, and that the City retained title to and could recapture the water in a manner facilitating its plan of operation.

Historically, great advances in science have occurred far in advance of the acceptance and application of the physical theories involved in the determination of legal rights. The law, by its very nature, is conservative and rests to a large extent on precedents which were established, in many instances, long prior to the developments of scientific progress. The courts have shown an increasing awareness in recent times of the implication of physical and economic situations on the former implacable harshness of the legal nature of property rights. In Pasadena v. Alhambra, supra, it was stated:

> "Although the law at one time was otherwise, it is now clear that an overlying owner or any other person having a legal right to surface or ground water may take only such amount as he reasonably needs for beneficial purposes."

and again:

> "Public interest requires that there be the greatest number of beneficial uses which the supply can yield."

With reference to the 1928 constitutional amendment, the court, in Gin S. Chow v. City of Santa Barbara, 217 Cal. 673, said:

> "That the constitutional amendment now under consideration is a legitimate exercise of the police power of the state cannot be questioned. It is the highest and most solemn expression of the people of the state in behalf of the general welfare. The present and future well-being and prosperity of the state depend upon the conservation of its life-giving water."

It is evident that with the legal basis for the acceptance of new and forward-looking concepts for the conservation of the water resources of semi-arid areas, legislation which can be shown to be necessary for the greatest possible development of the available resources in order that the "greatest good for the greatest number" may be accomplished can be adopted as a valid exercise of the police power and should be upheld by the courts. Since the surface storage and conservation of water is definitely limited in its application to the availability of suitable topographic sites, the time is rapidly being approached when full control and use of the vast underground storage capacity will be required in order to provide the necessary water supplies for full development.

Present Status of Development

At the present time, utilization of underground storage capacity is principally confined to haphazard local development and individual or community use of the water thus made available. In a few instances, deliberate attempts to replenish the supply by other than natural cyclic means has been attempted, with varying degrees of success.[2] In the usual case, the development is commenced by the earliest pumpers, whose enjoyment of this resource is

interfered with in the course of time by those who tap the supply at a later period. Since the annual accretion to storage is limited to that which naturally percolates to the water table, supplemented by underflow into the basin from adjacent areas, it is evident that there is, considering the underground basin as a storage reservoir receiving variable annual accretions, a definite supply which can be withdrawn in uniform annual amounts without permanently exceeding the safe yield of the basin. Withdrawals in excess of the amount, occasioned by the growing demand for water, will, with the passage of time, result in over-development of the basin, evidenced by progressive lowering of water levels over a long-time period and concurrent unability of the basin to return to a full reservoir status during the periods of above normal surface supplies. When this occurs, resort is had to the courts, as heretofore set forth, and the rights, expressed as annual withdrawals, for all users then pumping water from the basin are established. In a comprehensive adjudication it is evident that this procedure tends to inhibit all future use of the basin except by the parties to the original contest and those who derive their rights from such parties by sale or otherwise.

In general, such a procedure does not necessarily include a plan for the development and utilization of an imported supply. Under present law, it is difficult to make full use of the potential cyclic storage capacity and increase the average annual amount of water made available for future development. In California, the "court reference procedure," whereby such cases may be referred to the State Division of Water Resources for determination of the physical facts and recommendation for solution, is utilized by the courts in many cases. The availability of supplemental or imported water supplies is taken cognizance of in the investigation conducted by the Division and appropriate recommendations are made in the report rendered to the court. It is evident, however, that a feasible solution to the problem does not lie alone in the determination of rights to water after an overdraft occurs but also requires legislation wherein provision is made for complete administrative and technical control of the basin for all purposes. Current proposals for administrative determination of rights in underground water, similar to the procedures which have been applied for many years to surface waters, would merely substitute an administrative agency for the courts, without change in the basic philosophy. Although time and expense to the water users might well be saved by such procedures, no final solution to the over-all problem would be accomplished thereby.

The maximum development of the available water resources and the consequent economic development of the State can be realized only if the available ground-water storage capacity can be fully utilized for long-time holdover storage of surplus surface waters. Such planned utilization will enable full use to the possibilities inherent in the operation of the available reservoir space in the same manner and following the same general principles as in the operation of large surface reservoirs filling cyclic supply functions. The available capacity in underground reservoirs in California has been estimated to be in the order of 175,000,000 acre-feet, of which an estimated 133,000,000 acre-feet exists in the great Central Valley. An intensive investigation of the storage capacity in the Sacramento Valley portion of the Central Valley has been made by the United States Geological Survey and has resulted in the determination that this valley contains about 34,000,000 acre-feet of storage

2. "Ground-Water Recharge," by Finley B. Laverty, Journal Amer. Waterworks Assoc. Vol. 4, No. 6, 1952, pp. 677-681.

capacity in the depth range from 20 to 200 feet below ground surface. This capacity is, for all practicable purposes, largely unused at the present time. The possibilities of large-scale conservation works, making use of the subsurface storage capacity in an area of surplus water supply are almost unlimited. In addition to the conservation of surplus surface waters, the use of underground storage in the possible salvage of otherwise unusable waste waters from municipal and industrial developments is readily apparent. Such waters, of course, would have to be rendered suitable for admixture prior to being placed in storage in order that the quality of the underground waters would not be adversely affected.

Since planned utilization of the available underground storage capacity is inherent in a program of maximum conservation and use, it is evident that the retention of much of that portion of the water supply which is now wasted in outflow to the ocean and in excessive evaporation by phreatophytes will require the lowering of the water table during periods of less than average supply to a much greater extent than would otherwise occur in order to provide the storage capacity necessary for the maximum retention in the ensuing above-normal period. In such a program, the ground-water reservoir would be used for cyclic storage and would be operated in conjunction with surface reservoirs to provide a firm supply for both the overlying lands within the natural service area of the basin and for the exportation of surplus waters to areas of deficiency. Such operation will undoubtedly require maximum use of artificial replenishment of ground water and the coordinate operation of surface reservoirs so as to make such recharge feasible. This will require the over-all administrative control of an agency empowered to exercise jurisdiction between, as well as within, the geographical limits of individual basins. With reference to water available for export, for instance, it is actually a matter of little moment whether the water is used to replenish a local basin and later recovered and delivered to an area of deficiency or whether it is first exported to such an area and there stored underground for later use. The net result, or the net cost in the end product, should be about the same in both instances. Any plan for operation of underground storage which is approached from the purely local viewpoint will provide only temporary relief from periodic shortages and will eventually result in the waste of otherwise recoverable water to the detriment of areas in short supply.

A definite problem in the utilization of underground storage is the existence of present rights to water from such basins. If an attempt is made to coordinate usage of the storage capacity with the present pattern of withdrawals in a ground water basin, there will be inevitable conflict between the holder of rights to pumpage and the operators of the basin for reservoir purposes. It is probable that no user will ever complain during such periods as the water table is held at high levels and he consequently receives the benefit of lowered costs of pumping; however, at such times as the basin is deliberately lowered in order to firm supplies during dry periods, the administrative agency responsible for such operation would be the target of innumerable lawsuits, injunctions, and other hampering activities on the part of local water users. It is apparent then, that legislation providing for the utilization of underground storage capacity must, of necessity, also provide for appropriate adjustment with the owners of existing rights. Necessary water supplies will then be provided to the overlying service area by the agency operating the basin. A feasible method of evaluating the water right in such instances would be to establish the historical annual cost to the pumper and subtract such cost from the proposed price at which a supply will be

furnished for his lands; the difference can then be capitalized for an appropriate period, say fifty years, and the resulting amount termed the value of his right, for which he would receive compensation. Methods of control wherein the operating agency would compute the natural fluctuation which would occur in the absence of planned utilization and compensate individual users for excess costs of pumping during periods of lowered water table would equitably require that the user be charged an amount over and above his cost of pumping during periods of high water table and would result only in interminable administrative difficulty.

WATER CONTROL AGENCIES

It is evident from the foregoing discussion that the enabling legislation to permit full utilization of ground-water storage capacity should provide for an organization with state-wide powers to control such usage. The usual type of public district organization, which in this case would be confined to individual ground-water basins or, in the maximum heretofore proposed areal extent, to entire stream basins, would not have the inherent authority necessary to provide for the large-scale transfer of water supplies from areas of surplus to areas of deficiency. The limited organization, therefore, would not be able to accomplish the purposes for which the program was conceived and operated.

Enabling legislation designed to accomplish state-wide control of the ground-water storage capacity should provide for:

a) the appointment or election of a governing board;
b) the purchase, or other adjustment of conflicts with, existing water rights;
c) the conservation of the available supply through maximum use of underground storage;
d) the transportation of water supplies between stream basins;
e) the development and distribution of water to operating agencies for irrigation, municipal, and other uses;
f) the imposition of general taxation in order to share the burden of costly supplies, contributing to the general prosperity of the state, among those who ordinarily secure their water supplies by other means;
g) the artificial recharge of underground basins;
h) the treatment and conservation of waste waters;
i) the coordinated operation of surface reservoirs which are an integral part of the combined system; and
j) the issuance of either or both revenue and general taxation bonds to defray the capital investment of the operation.

Although the powers enumerated above are far-reaching, anything less will inevitably result in failure to develop the available supplies to the maximum extent by means of planned operation of cyclic storage and redistribution of supplies on a statewide basis from areas of surplus to those of deficiency. Above all, the water supply contributing to the development of the modern community must not be permitted to be subject to intersectional jealousies or political expediency.

OPERATION OF UNDERGROUND STORAGE

The capability of underground storage exists in any geological formation in which interstices are present; however, the particular storage capacity herein discussed is that which exists in the broad alluvial valleys and coastal plains across which flow the major streams of the State. Underground storage reservoirs are usually far larger in extent and in total storage capacity than available surface reservoir sites. Natural annual recharge, however, is usually much less, in proportion to storage capacity, than the annual supply to surface reservoirs. Ground-water reservoirs may, in years of deficient surface supplies, be drawn down to the greatest practicable extent whereas surface storage, because of lesser capacity, has a definite limited annual ability to yield a water supply for beneficial use. Ground-water reservoirs serve frequently as regulators of stream flow, maintaining such flow over periods of deficient precipitation. In the operation of underground storage, the average annual discharge may exceed the annual recharge for much longer periods than is possible with surface reservoirs, if the long-time average annual recharge and discharge are maintained in hydrologic equality.

The two principal types of ground-water reservoirs commonly found in alluvial formations are free ground-water reservoirs in which the water table represents the upper surface of the reservoir, and in which change of storage is represented by rising or falling of the water table and is equal to the product of the cubical contents of the material between the water table at the beginning and end of the period and the average specific yield of the material in which the change in storage occurs; and artesian ground-water reservoirs in which the water is confined under pressure and upon release will rise above the physical limits of the upper surface of the water in storage, and in which change in storage can occur only in the forebay area, a free ground-water reservoir at the head of the artesian area. In many artesian reservoirs, occasional changes will take place in the cubical capacity available due to compression of the overlying impermeable strata. This change in capacity is relatively minor and is in reality a change in the transmission capacity of the reservoir rather than the storage capacity, since storage in such an aquifer becomes important only after the forebay has been dewatered to the extent that the upper physical surface of the underground water has become a free water table due to receding from contact with the overlying confining strata. Change in storage capacity may occur in a free ground-water reservoir due to consolidation of the fill material, but available data on this aspect of loss of storage capacity does not provide a basis for its evaluation.

In order to perform a regulating function in the hydrologic cycle, a ground-water reservoir must maintain a constant cycle of recharge and discharge. In the natural state, and over a period of time during which the aggregate supply approaches the long-time mean, recharge and discharge are equal and no net change in storage occurs. In this process, a regular regimen is developed which is followed throughout a period of wet and dry years. During and following a period of above-normal supply, the water table rises, natural discharge is increased, high water tables contribute to the disposal of surplus water by evaporation from moist areas and transpiration by phreatophytes. With a succession of below-normal seasons, the water table falls, the moist areas are dewatered, subsurface outflow is decreased, and phreatophytes wither due to lack of adequate supply. This cycle of alternately rising and falling water table is repeated interminably as time continues. Under active development, this regimen is affected by artificial extractions. In the

early period of such development, water is actually mined from storage. In other words, an excessive amount is removed from storage in order to lower the water table rapidly to such an extent that the average annual recharge will not again raise the water table to an elevation where undue waste occurs. This excess removal of water in the early development period cannot be continued over a long-time period unless means is found to increase the natural recharge to the extent necessary to maintain such withdrawals.

The planned utilization of underground storage must envision the lowering of the water table in the reservoir during a period of dry years and the subsequent recharge and storage of surplus flows during the ensuing wet period. Unless sufficient storage capacity is made available, a portion of the surface supply during this period must be wasted; on the other hand, too great a lowering will result in the inability to fully recharge the basin due to inadequacy of the available supply. Such loss of storage would occur in the zone closest to the ground surface where recovery costs are least. A concurrent problem, on which extensive research activities have been, and are presently being, conducted, is the practicability of artificial recharge by the use of the surplus surface water available.[2, 3] It is clear that the capacity of the underground reservoir to provide cyclic storage for the long-time average annual supply is solely dependent upon the rate at which such surface supplies may be placed in storage in the underground basin. Present experimental projects in inducing such artificial recharge are being conducted in many localities, including experiments in the use of chemical additives and mechanical aids to maintain percolation rates,[4] and in the use of recharge, or injection, wells. Significant contributions to ground water are also made by percolation from surface conduits, from rivers and streams, and from deep percolation of water applied to lands for the irrigation of crops. Much recent interest has been aroused in the possibilities in recovery of large quantities of otherwise waste water through reclamation of spreading of sewage.

A further operating problem arises in maintaining the water table at an elevation below the root zone of overlying vegetation, and below the limits of capillary action in order to reduce the loss of storage due to excessive evapotranspiration. Other losses, principally those due to water-loving vegetation and subsurface outflow from the basin will occur, but these are also subject to a measure of control. Subsurface outflow is usually dependent upon the elevation of the water table at a point some distance upstream, or upbasin, from the point of outflow, and such water may in large measure be salvaged for use as a part of the annual supply by a program of pumping from that part of the reservoir closest to the subsurface outlet. Much can be done in programming the extractive operations so that the maximum beneficial effect can be gained from the operation of the underground reservoir. The pattern of pumping should be planned so as to take the greatest advantage of the usable storage capacity and should be definitely related to the geologic structure of the basin, the areas of natural and artificial recharge, the transmissibility of the basin materials, the areas of use, both local and area of diversion for

3. "Spreading Water for Storage Underground," by A. T. Mitchelson and Dean C. Muckel, Technical Bulletin No. 578, U. S. Department of Agriculture, Washington, D. C., 1937.
4. "Some Factors Involved in Ground Water Replenishment," by R. S. Bliss and C. E. Johnson, Trans. American Geophysical Union, Vol. 33, No. 4, 1952, pp. 547-558.

export, the necessity and amount of drainage necessary for salt balance, and the desirability of controlling the subsurface outflow and effluent seepage from the basin.

The average annual firm supply which can be made available by operation of the underground reservoir will to a large extent, be limited by (1) the rate of recharge, (2) the maximum economic cost of pumping, (3) the effect of the operation on the quality of the water supply, and (4) the sum of unavoidable losses. The economic cost of pumping would appear to have its greatest effect on developments primarily for irrigation purposes and would limit the maximum permissible cost to the residual between income derived from irrigated crops and the total of all costs of production other than those attributable to water supply. In the case of municipal and industrial supplies, the cost of pumping would have a greatly diminished effect as other general economic factors, such as the desirability of continued full employment, necessity of water for the purpose of maintaining life, and similar considerations would have a decided bearing on the practicability of pumping water from great depths. The extent of works constructed to facilitate recharge will be determined by the other three factors mentioned above, since recharge at a rate in excess of that necessary to assure a full supply reservoir at the conclusion of a wet period will result only in excessive loss through waterlogging of lower portions of the basin and uneconomic outflow.

Special operating problems will be evidenced in some basins due to local geographic and geologic factors. The problem of saline waters is such a one in many basins of California.[5] The prevention of sea-water intrusion is a continuing problem in coastal ground-water basins,[6] many of which have been drawn down to such an extent that sea water has presently penetrated into the aquifers with deleterious effect on the usability of the supply. Experiments in the prevention of such intrusion of the operation of a line of coastal injection wells have been made during the past few years by the Division of Water Resources and the Los Angeles County Flood Control District,[7] and a research project covering the same general problem has recently been completed by the University of California.[8] Large portions of the Central Valley of California were formerly overlain by an arm of the ocean, and saline waters at depth underlie the presently usable fresh waters. Excessive drawdown of the water table and heavy pumping rates have a tendency to cause these saline waters to rise in local areas and mix with the high quality waters in the upper zones. Other problems arise through intrusion by lateral underflow of ground waters of inferior quality when the free water table is lowered

5. "Water Quality Problems in California," by Harvey O. Banks and Jack H. Lawrence, Trans. Amer. Geophysical Union, Vol. 34, No. 1, 1952, pp. 58-66.
6. "Sea Water Intrusion into Ground Water Basins Bordering the California Coast and Inland Bays," by Harvey O. Banks, George B. Gleason and Raymond C. Richter, Report No. 1, Water Pollution Investigations, Division of Water Resources, State of California, 1950.
7. "Report on Tests for the Creation of Fresh Water Barriers to Prevent Salinity Intrusion Performed in West Coastal Basin, Los Angeles County," by Finley B. Laverty, L. W. Jordan, and H. A. van der Goot, Los Angeles County Flood Control District, 1951.
8. "Report on Sea Water Intrusion," by Thomas R. Simpson, James A. Harder, and Leung-ku Lau, Sanitary Engineering Research Laboratory, University of California, April, 1954.

sufficiently to permit a differential head to occur. In pressure aquifers, problems arise due to downward infiltration of poor quality perched waters through defective wells when the underlying head is reduced through heavy pumping. It would appear that in large scale operations, many of these problems would not be confined to individual basins, and hence a multiplicity of ground-water basin districts concerned with the long-time cyclic management of the underground reservoirs would be unable to coordinate their operations to the extent necessary to effect the best use of the available storage capacity.

Illustrative Example

In order to emphasize the beneficial results of coordinated operation of surface and underground storage, an example of the utilization of an hypothetical underground basin is hereinafter presented. The basin was operated in conjunction with surface storage over a thirty-year period, 1914-15 to 1943-44, using the full natural flow of the Tuolumne River, tributary to the Central Valley of California, as the assumed supply. Basic assumptions made for the study were as follows:

Annual Demands

Irrigation	960,000	acre-feet, over a period of seven months
Municipal	200,000	acre-feet, of which 42% occurred during the winter period and 58% during the summer
Evaporation	50,000	acre-feet from the surface reservoir
Export	300,000	acre-feet constant flow
Total	1,510,000	acre-feet

Average Annual Supply	1,751,000 acre-feet
Dry Period Annual Supply	1,550,000 acre-feet
Maximum Surface Reservoir Capacity	1,200,000 acre-feet
Maximum Usable Underground Capacity	1,800,000 acre-feet
Surface Minimum Storage	50,000 acre-feet
Recharge Capacity	540,000 acre-feet per annum 45,000 acre-feet per month

It was assumed that subsurface outflow from the ground-water unit would occur at a maximum rate of 48,000 acre-feet per year when the basin was at maximum capacity and would vary in a linear relationship with the storage.

In the first operation study the surface reservoir was operated to supply the annual demand to the maximum extent possible, and to furnish the water required for recharge to the underground basin. Deficiencies in surface supplies were augmented by withdrawals from underground storage. The surface storage was depleted to the maximum extent annually, and the ground-water storage was retained at maximum capacity for the greatest possible portion of the total time. The second study comprised the simultaneous recharge to and withdrawal from the ground-water basin in practically all years of the period in conjunction with partial supply of the annual demand from surface storage. It was found that the method of operation had little effect on the long-time results so long as the annual withdrawal from both surface and

underground storage was held within reasonable limits. In the second study, utilizing annual withdrawals from underground storage, a slight reduction in the total loss due to subsurface outflow was effected, due to a somewhat lower average elevation of water table. A third study, operating only the available surface storage, was made in order to compare results, in the form of percentage of conservation of the total available supply, obtained through the use of underground storage capacity. While some water could have been made available for export from operation only of surface storage during practically all years, it would have varied greatly in amount and time of occurrence and would have necessitated the use of excessively large transmission capacity in order to make it available to the area of import. Likewise, it would have been necessary to have operated a ground-water reservoir in the area of import in order to re-regulate the varying annual supply. While in the operation of coordinated ground and surface storage, when considering export supplies, it does not matter from an engineering standpoint whether the supply is used to charge a basin in the local area and later pumped and forwarded to the area of use, or whether it is first exported and there regulated by underground storage, the economics of transmission will probably define the most feasible solution. The results of the above studies are briefly set forth below:

	OPERATIONAL STUDY NUMBER, (Quantities in 1,000 acre-feet except as noted)		
	1	2	3
Storage			
Beginning of Period	50	50	50
End of Period	2,375	2,387	848
Annual Yield	1,510	1,510	1,210
Total Spill	4,325	4,335	15,512
Subsurface Outflow	1,068	988	
Deficiency - 1934	485	426	79
In per cent of demand	32.1	28.2	6.5
Conservation, in per cent of total water available	90.7	90.9	70.5

The important fact illustrated by the study is the tremendous increase in conservation of the available supply which is creditable to the operation of the ground-water storage capacity. It will also be noted that in operational study No. 2, it was possible to meet demands with a lesser deficiency during the year (1934) of maximum exhaustion of supply over the dry period which extended from 1923-24 to 1934-35.

ACKNOWLEDGMENT

Much of the subject matter contained herein has been expressed in similar ways by many others to whom the writer is indebted for basic concepts. It is particularly desired to state that the opinions and conclusions expressed herein are solely those of the writer and are not to be construed to indicate or represent the policies of the Division of Water Resources of the State of California.

PROCEEDINGS-SEPARATES

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JUNE: 444(SM)[e], 445(SM)[e], 446(ST)[e], 447(ST)[e], 448(ST)[e], 449(ST)[e], 450(ST)[e], 451(ST)[e], 452(SA)[e], 453(SA)[e], 454(SA)[e], 455(SA)[e], 456(SM)[e].

JULY: 457(AT), 458(AT), 459(AT)[c], 460(IR), 461(IR), 462(IR), 463(IR)[c], 464(PO), 465(PO)[c].

AUGUST: 466(HY), 467(HY), 468(ST), 469(ST), 470(ST), 471(SA), 472(SA), 473(SA), 474(SA), 475(SM), 476(SM), 477(SM), 478(SM)[c], 479(HY)[c], 480(ST)[c], 481(SA)[c], 482(HY), 483(HY).

SEPTEMBER: 484(ST), 485(ST), 486(ST), 487(CP)[c], 488(ST)[c], 489(HY), 490(HY), 491(HY)[c], 492(SA), 493(SA), 494(SA), 495(SA), 496(SA), 497(SA), 498(SA), 499(HW), 500(HW), 501(HW)[c], 502(WW), 503(WW), 504(WW)[c], 505(CO), 506(CO)[c], 507(CP), 508(CP), 509(CP), 510(CP), 511(CP).

OCTOBER: 512(SM), 513(SM), 514(SM), 515(SM), 516(SM), 517(PO), 518(SM)[c], 519(IR), 520(IR), 521(IR), 522(IR)[c], 523(AT)[c], 524(SU), 525(SU)[c], 526(EM), 527(EM), 528(EM), 529(EM), 530(EM)[c], 531(EM), 532(EM)[c], 533(PO).

NOVEMBER: 534(HY), 535(HY), 536(HY), 537(HY), 538(HY)[c], 539(ST), 540(ST), 541(ST), 542(ST), 543(ST), 544(ST), 545(SA), 546(SA), 547(SA), 548(SM), 549(SM), 550(SM), 551(SM), 552(SA), 553(SM)[c], 554(SA), 555(SA), 556(SA), 557(SA).

DECEMBER: 558(ST), 559(ST), 560(ST), 561(ST), 562(ST), 563(ST)[c], 564(HY), 565(HY), 566(HY), 567(HY), 568(HY)[c], 569(SM), 570(SM), 571(SM), 572(SM)[c], 573(SM)[c], 574(SU), 575(SU), 576(SU), 577(SU), 578(HY), 579(ST), 580(SU), 581(SU), 582(Index).

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FEBRUARY: 608(WW), 609(WW), 610(WW), 611(WW), 612(WW), 613(WW), 614(WW), 615(WW), 616(WW), 617(IR), 618(IR), 619(IR), 620(IR), 621(IR)[c], 622(IR), 623(IR), 624(HY)[c], 625(HY), 626(HY), 627(HY), 628(HY), 629(HY), 630(HY), 631(HY), 632(CO), 633(CO).

MARCH: 634(PO), 635(PO), 636(PO), 637(PO), 638(PO), 639(PO), 640(PO), 641(PO)[c], 642(SA), 643(SA), 644(SA), 645(SA), 646(SA), 647(SA)[c], 648(ST), 649(ST), 650(ST), 651(ST), 652(ST), 653(ST), 654(ST)[c], 655(SA), 656(SM)[c], 657(SM)[c], 658(SM)[c].

APRIL: 659(ST), 660(ST), 661(ST)[c], 662(ST), 663(ST), 664(ST)[c], 665(HY)[c], 666(HY), 667(HY), 668(HY), 669(HY), 670(EM), 671(EM), 672(EM), 673(EM), 674(EM), 675(EM), 676(EM), 677(EM), 678(HY).

MAY: 679(ST), 680(ST), 681(ST), 682(ST)[c], 683(ST), 684(ST), 685(SA), 686(SA), 687(SA), 688(SA), 689(SA)[c], 690(EM), 691(EM), 692(EM), 693(EM), 694(EM), 695(EM), 696(PO), 697(PO), 698(SA), 699(PO)[c], 700(PO), 701(ST)[c].

JUNE: 702(HW), 703(HW), 704(HW)[c], 705(IR), 706(IR), 707(IR), 708(IR), 709(HY)[c], 710(CP), 711(CP), 712(CP), 713(CP)[c], 714(HY), 715(HY), 716(HY), 717(HY), 718(SM)[c], 719(HY)[c], 720(AT), 721(AT), 722(SU), 723(WW), 724(WW), 725(WW), 726(WW)[c], 727(WW), 728(IR), 729(IR), 730(SU)[c], 731(SU).

c. Discussion of several papers, grouped by Divisions.

e. Presented at the Atlantic City (N.J.) Convention in June, 1954.

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